PART 7

APPENDICES

Appendix 7.1 Lake Michigan Mass Balance Project (LMMBP) PCB Peer Review Report

Kenneth R. Rygwelski
U.S. Environmental Protection Agency
Office of Research and Development
National Health and Environmental Effects Research Laboratory
Mid-Continent Ecology Division
Large Lakes and Rivers Forecasting Research Branch
Large Lakes Research Station
9311 Groh Road
Grosse Ile, Michigan 48138

7.1.1 Executive Summary

The United States Environmental Protection Agency (USEPA), National Health and Environmental Effects Laboratory (NHEERL), Mid-Continent Ecology Division at Grosse Ile, Michigan in cooperation with the USEPA Great Lakes National Program Office (GLNPO), conducted a polychlorinated biphenyl (PCB) transport and fate mass balance modeling study of PCBs in Lake Michigan to determine strategies for managing and remediating this toxic chemical in the lake basin. Some specific programs that this effort support include the Lake Michigan Lake-wide Management Plan (LaMP) and the Great Lakes Water Quality Agreement (GLWQA). Within the ecosystem approach, the Lake Michigan Mass Balance Project (LMMBP) models account for the sources, sinks, transport, fate, and food chain bioaccumulation of PCBs. The calibrated models offer an opportunity for running various PCB load reduction scenarios to get an insight on the effects to the lake ecosystem. Model forecasting of PCB concentrations in lake trout is one of the primary end-points of the investigation as it relates to both ecosystem and human health. In addition, demonstration of a whole lake Total Maximum Daily Load (TMDL) process to yield a desired target PCB concentrations in lake trout has been achieved. A significant factor that differentiates this study from other PCB transport and fate modeling projects is that PCBs were modeled as single PCB congeners to predict total PCBs. Also, a high-resolution hydrodynamic model was applied and a eutrophication model was used to generate the primary productivity solids in this system where autochthonous solids production is significant and plays an important role in describing PCB transport. Mass balance estimates indicate that the lake system is losing approximately 2,000 kg/year of PCBs. Also, the bioaccumulation model predicts that the target level for unrestricted consumption in lake trout (0.075 ppm for whole fish) was forecasted to be achieved for five to six year-old lake trout between the years 2025 and 2035.

The main sampling activity for the project was conducted in 1994 through 1995; however, a PCB screening-level model called MICHTOX was developed and running PCB simulations before the LMMBP began. This model was developed to gain an initial insight into the PCB transport and fate in Lake Michigan including its biota. Later on, the MICHTOX model was run again using the newer data collected from the LMMBP. The more advanced PCB and support models included a hydrodynamic model called Princeton Ocean Model (POM), a eutrophication model called LM3-Eutro, and a 41

segment PCB model called LM2-Toxic. The output from the LM2-Toxic was used to define the exposure concentration for the bioaccumulation model called LM-Food Chain. Development of a high resolution PCB model (LM3-Toxic) is proceeding, and is discussed in the Modelers' Comments section.

On July 27 - 28, 2004, peer reviewers representing modelers in academia, research, and the USEPA, convened at the Crowne Plaza Hotel in Romulus, Michigan to review the LMMBP PCB models (Figure 1). Prior to this review, a June 2004 draft copy of "Results of the Lake Michigan Mass Balance Project: PCBs Modeling Report" prepared by the Large Lakes and Rivers Forecasting Research Branch, Mid-Continent Ecology Division, NHEERL, Office of Research and Development (ORD), USEPA at Grosse Ile, Michigan was provided to each of the peer reviewers. In general, the review panel agrees that the model construct (spatial, temporal, process resolution) and application is consistent with the problem definition for which the model was developed and for the available resources. In addition to providing a comprehensive review of the model, the panel also provided detailed suggestions for future model improvements. Most of the panel's comments were captured at the meeting and are identified as "consensus" comments. James Martin provided additional post-meeting comments (see Section 7.1.5), and the modelers' responses to his questions follow the responses to the consensus comment section. In addressing the review comments, we had to carefully consider where to apply available resources and prioritize actions that help to ensure model integrity. Hopefully our responses reflect this balance. Responses identify actions that have been taken, are on-going, or will be conducted in the future. The USEPA wishes to thank the panel for their willingness to participate in this review and for their constructive comments.

7.1.2 LMMBP Peer Review Panel

Robert B. Ambrose, Jr., P.E.
Environmental Engineer
Ecosystems Research Division
National Exposure Research Laboratory
U.S. Environmental Protection Agency
Office of Research and Development
960 College Station Rd.
Athens, Georgia 30605
Voice: 706-355-8229; Fax: 706-355-8104
ambrose.robert@epa.gov

Joel E. Baker, Ph.D.
Professor
Chesapeake Biological Laboratory
P.O. Box 38
2108 Fowler Laboratory
University of Maryland
1 Williams Street
Solomons, Maryland 20688-0038
Voice: 410-326-7205
baker@cbl.umces.edu

Ken Drouillard, Ph.D.
Assistant Professor
Great Lakes Institute for Environmental Research
Biological Sciences Department
401 Sunset Avenue
Windsor, Ontario Canada N9B 3P4
Voice: 519-253-3000 Ext. 4744
kgd@uwindsor.ca

Barry Lesht, Ph.D.
Department of Energy, Acting Director of Environmental Research Division
Argonne National Laboratory
9700 S. Cass Avenue
Argonne Illinois 60439
Voice: 630-252-4208 Fax: 630-252-2959
bmlesht@anl.gov

James L. Martin, Ph.D., P.E.
Professor and Kelly Gene Cook, Sr. Chair in Civil Engineering
Department of Civil Engineering
Mississippi State University
P.O. Box 9546
222 Walker Engineering Building
Mississippi State, Mississippi 39762-9546
Voice: (662) 325-7194; Fax: (662) 325-7189
jmartin@engr.msstate.edu

7.1.3 LMMBP PCB Charge to Peer Reviewers

The members of the Peer Review Panel have been assembled by the USEPA GLNPO because they are experts in multimedia mass balance modeling and have expertise in one or more of the multimedia

Table 7.1.1. Agenda – Lake Michigan Mass Balance PCB Modeling Peer Review, Crowne Plaza Hotel, 8000 Merriman Road, Romulus, Michigan 48174 at Detroit Metropolitan Airport, Romulus, Michigan, July 27 and 28, 2004

Time	Tuesday's Agenda	Speaker
8:20 am	Welcome/Introductions and Project Goals/Objectives/Uses	P. Horvatin
8:40 am	Agenda Overviews/Previous Reviews	J. Keough
8:50 am	Charge to Peer Review Panel	G. Warren
9:00 am	PCB Background and History	R. Kreis
9:15 am	PCB QA Report	L. Blume
9:30 am	PCB Data Summary/Representativeness	R. Rossmann
9:45 am	Questions and Discussion	
10:00 am	Break	
10:15 am	Modeling Introduction/Overview	R.. Kreis
10:40 am	Atmospheric Load Modeling	D. Hornbuckle/J. DePinto
11:10 am	Questions and Discussions	
11:20 am	Tributary Load Modeling	D. Hall
11:50 am	Questions and Discussion	
12:00 pm	Lunch	
1:00 pm	MICHTOX Level 1 Modeling	D. Endicott
1:45 pm	Questions and Discussion	
2:00 pm	Hydrodynamic Modeling and POM to WASP Linkage	D. Beletsky
2:30 pm	Questions and Discussion	
2:45 pm	Break	
3:00 pm	Eutrophication Modeling - Autochthonous Carbon Production	J. Pauer
3:30 pm	Questions and Discussion	
3:40 pm	PCB Fate and Transport Modeling	Xiaomi Zhang
4:10 pm	Questions and Discussion	
4:20 pm	Food Chain Bioaccumulation Modeling	Xin Zhang
4:50 pm	Questions and Discussion	
5:00 pm	Remaining Issues/Wednesday's Agenda	R. Kreis
5:30 pm	Adjourn for the Day	

Time	Wednesday's Agenda	Speaker
8:00 am	Comparisons of Models	K. Rygwelski
8:30 am	Questions and Discussion	
8:40 am	Future Plans and Applications	R. Kreis
9:10 am	Questions and Discussion	
9:20 am	Summary of Peer Review Panel Recommendations	R. Kreis
10:00 am	Break	
10:15 am	Wrap-Up Session - Final Discussion and Debriefing by Reviewers	
12:00 pm	Adjourn	

aspects of this modeling approach. Panel Reviewers are expected to provide an objective, unbiased review of the Lake Michigan Mass Balance PCB Modeling: science, best modeling practices, conduct, and supporting components. Panel Review comments should be verbally summarized at the end of the review and then provided in written form, cognizant of constraints in data availability, staff, and financial resources associated with the project. Written comments on the format and content of the project documentation can be provided, if appropriate.

7.1.3.1 Overall Multimedia Ecosystem Modeling Approach

Does the suite of models applied, including atmospheric and tributary load calculation models/methodologies, hydrodynamics model, autochthonous solids (eutrophication) model, water column and sediment transport and fate models, and food chain bioaccumulation model, represent an integrated approach to ecosystem modeling? Are these models, in combination, state-of-the-art? What are the strengths and weaknesses of the overall approach?

7.1.3.2 Overall Model Performance

Overall, how well does the model suite represent physical, chemical and biological processes? How consistent are the modeling concepts and assumptions with current scientific knowledge? Are the processes being depicted at the spatial and temporal scales appropriate/adequate for the issues being addressed and data availability? Overall, how well are transport, exchange, and partitioning processes for PCBs accounted for? Are the food web, trophic structure, and processes which affect bioaccumulation represented accurately? Overall, how well is food chain bioaccumulation of PCBs in Lake Michigan represented? Are model algorithms used to describe processes appropriate (complexity versus simplification)? Have the data been adequately and fully utilized in the modeling? What are the strengths, weaknesses, and uncertainties of the overall modeling performance?

7.1.3.3 Suitability for Management

In terms of their predictive capability related to transport, fate, and bioaccumulation of PCBs in lake trout, is the suite of models and application sufficient to evaluate and guide potential PCB load reduction strategies for Lake Michigan? What are anticipated modeling strengths and weaknesses for management uses?

7.1.4 Modelers' Responses to Peer Review Comments

1. How do you reconcile the difference in peak PCB production versus peak loads for the hindcast run?

Modelers' Response – The explanation for this difference is not readily apparent. A similar difference has been noted for Lake Ontario (Gobas *et al.*, 1995). Peak production occurred in 1970. Gobas *et al.* (1995) found the best overall agreement between observed and predicted total PCB concentrations in water, sediment, and biota occurred when peak loading was assumed to occur in 1961. One would not expect peak loading to necessarily occur in the same year as peak production. Much of the PCBs produced were used in transformers and other sealed sources which would not have an impact on the environment until product failure occurred. It is believed that most of the significant loading of PCBs to Lake Michigan came from PCBs that were used for other purposes. The use of these PCBs in the basin does not appear to coincide with production. Within the basin, the first noted use of PCBs was at Waukegan, Illinois in 1948 when Outboard Marine Corporation purchased hydraulic fluid with PCBs. From the mid-1950s to mid-1960s, PCBs from deinking were loaded to the Kalamazoo River. In the 1950s, PCBs were used in the Green Bay area for production of PCB-coated carbonless copy papers. These discharges to the Fox River peaked in 1969-1970. The use of PCBs for these papers was phased-out in 1971-1972. In the 1960s, industrial PCBs were loaded to Sheboygan Harbor. Thus it appears that PCB use in the basin began in 1948 and ended in 1972. The loadings over time from these uses of PCBs is not currently documented; however, it appears that PCB loadings to the Lake Michigan basin do not coincide with production or sales figures. This discussion will be included in Part 1, Chapter 7 of the report.

2. POM: Extend the hydrodynamic record from two years to ten years.

Modelers' Response – Currently, funding is not available to extend the POM modeling from two years to ten years. When preparing to conduct forecasts, we were concerned about how representative POM (1994 and 1995) results would be when repeated along with water temperature, velocities, and dispersion coefficients for LM2-Toxic (PCB) and LM3-Eutro (nutrients and carbon) model runs extending beyond the two-year LMMBP period. The POM model used lake conditions and forcing functions present March 31,1982 through November 20, 1983 for calibration purposes. Comparing lake and atmospheric conditions such as wave height, air temperature, lake levels, tributary flows, and precipitation for the 1982-1983 and the LMMBP period 1994-1995 with the historical record, we found that neither of the two-year periods were at any extreme from means. Based on this review, we believe that the two years of hydrodynamic modeling fairly represent average lake conditions. More discussion on the representativeness of the 1994-1995 period can be found in Part 1-Introduction and Chapter 4 of the report.

3. LM3-Eutro: Why does the model not predict dissolved silicon beyond 0.7? Was the code checked for possible errors? Identify Green Bay stations on the model versus observed plots.

Modelers' Response – This question is related to Figure 2.5.3 in the June 2004 draft copy of "Results of the Lake Michigan Mass Balance Project: PCBs Modeling Report." Please note that the axes in this figure were incorrectly labeled. The abscissa axis should be labeled "model results", and the ordinate axis should be labeled "field data." The dissolved silica output from the model was examined carefully. Although it appears that the model does not predict values higher than 0.7 mg/L (Figure 2.5.3), closer inspection of the model output reveals that the majority of the predicted values are relatively evenly distributed between 0.4 and 0.76 mg/L, with a few values as high as 0.78 mg/L. A limitation of the LM3-Eutro model was the absence of a fully-developed sediment submodel that reflected seasonal variations. User-defined soluble reactive phosphorus, ammonia, dissolved silica, and dissolved organic carbon sediment fluxes were used to provide an estimate of the sediment feedback. However, these fluxes were constant values in space and time and were selected to provide a reasonable estimate of annual averages. Due to this limitation, the model underestimated the silica build-up at the bottom of the lake during the late summer months caused by the slow decay of the biogenic silica, which settled to the bottom during the spring and early summer diatom blooms, and its potential resuspension. It is believed that this is the major reason why model output values are less that 0.8 mg/L whereas several field values are well above 1 mg/L. There is little difference between observed silica concentrations in Green Bay and the open lake with large seasonal variations at both locations. In Lake Michigan, the observed silica range is between 2.1 and 0.04 mg/L, while in Green Bay it ranges between 1.58 and 0.13 mg/L.

4. LM2-Toxic: Run the model with a conservative tracer and check that mass balances (set initial conditions and boundary concentration = 1).

Modelers' Response – This test was completed very successfully. By setting initial and boundary concentrations of an assumed conservative tracer equal to 1 mg/L in both the water column and sediment segments with no external load, no gas exchange, and no partitioning process, the model was run for a short-term simulation (two years) and a long-term simulation (60 years). The results from the model runs show no change for the two-year model run in all media. For the long-term run, an extremely small change (0.001%) was found in water column segments with roughly a 0.5% change in sediment segments.

5. LM2-Toxic: Consider adding subsurface benthic layers below the surficial layer. It is likely that higher PCB concentrations reside in the deeper layers. Look at historical data.

Modelers' Response – There are subsurface sediment layers (called ghost layers) defined in the current LM2-Toxic segmentation. A quasi-Lagrangian framework is used to allow a moving sediment-water interface. There is no mass exchange between the mixed surficial sediment layer and subsurface sediment layer, and between two adjacent subsurface layers through mixing or diffusion processes. The cores that demonstrate the high PCB concentrations in deeper layers are found in the depositional zones where the potential for resuspension is minimal. Furthermore, mass transfer *via* diffusion between deeper layers is likely to be minimal for hydrophobic PCBs (see response to comment 14). A detailed description of the semi-Lagrangian sediment bed option is detailed in Part 4, Chapter 3, Section 4.3.4.2.3 of the report and IPX 2.74 documentation (Velleux *et al.*, 2000).

6. LM2-Toxic: Recheck assumptions on scenarios with attenuation rates for tributary loads and wet/dry atmospheric deposition. Check Hites' data against assumed decline in vapor concentration.

Modelers' Response – The half-life of the PCB decline in tributary and vapor phase loadings were assumed to be 12.5 years and six years, respectively, in our model runs for "natural attenuation." These rates are consistent with the PCB tributary and atmospheric loading rates of decline calculated and used by other researchers (Velleux and Endicott, 1994; Endicott, 2002; Marti and Armstrong, 1990; Hillery *et al.*, 1997; Schneider *et al.*, 2001). Further examination of additional data has not revealed any change to these assumptions. See Part 3, Chapter 3 of the report and Endicott (2005) for documentation of materials used for hindcasts and forecasts for MICHTOX and LM2-Toxic. Eventually, Attachment 4 will become a stand-alone ORD publication. See Part 4, Chapter 6, Paragraph 4.6.3 for documentation of sources of information used for forecasts for the LM2-Toxic. A detailed description of the uncertainties that would have an impact on hindcast and forecast choices will be detailed in a revision of the report in Part 1, Chapter 7.

7. LM2-Toxic: Compare model projections to water data post-1998 (southern Lake Michigan).

Modelers' Response – Post-1998 data for southern Lake Michigan have been located. These data will be compared with the model's long-term projections as part of the model verification. The results of the comparison will be detailed in a revised edition of the report. Additional verification of the model will occur after data collected in 2005 are available.

8. LM2-Toxic: The Panel recommended that a Monte Carlo uncertainty analysis be performed using a steady-state version of the model.

Modelers' Response – This is certainly a valid suggestion. However, given the complexity of the model and the number of solids (three solids) and PCB congeners (54 congeners) simulated in the model, it could be very costly and time-consuming to do the recommended Monte Carlo uncertainty analysis on even a few selected critical parameters used in a steady-state version of the model. In addition to the uncertainties associated with the parameters defined by chemical and biochemical processes conceptualized in the model, water transport, solid cycling rates, numerical algorithms used in the model, and data input into the model are all subject to a certain error, and this error propagates in the model results. The uncertainties associated with these errors could be much greater than the ones only related to the chemical-specific parameters. See Part 4, Chapter 5, Section 4.5.4 for details on the tasks conducted to reduce the uncertainties caused by water transport and solid cycling rates. If computing resources and manpower become available, this issue will be addressed in the future.

9. LM2-Toxic: In regards to solids dynamics (radioisotope calibration), the Panel requested that the Modelers' examine the decline rate and add more recent data.

Modelers' Response – We will examine the decline rate and add more recent data in the future as available.

10. Peer Review Panel: LM2-Toxic/Eutro: How sensitive is the PCB model to primary productivity changes versus sediment net resuspension changes?

Modelers' Response – The suggested sensitivity analysis has been thoroughly investigated. For a 50% increase or decrease in primary production corresponding to the primary production generated from LM3-Eutro for the 1994-1995 period, the LM2-Toxic model was tested for both a short-term (the two-year calibration) period and a long-term (62-year) period. The results from the sensitivity analyses were compared to the results from the LM2-Toxic model base runs (i.e. 1994-1995 calibration run and long-term Constant Condition Scenario). See Part 4, Chapters 5 and 6 for detailed descriptions of both of these base runs. The general results from the tests are: 1) The solids concentrations (DOC – Dissolved Organic Carbon, BIC – Biotic Carbon, and PDC – Particulate Detrital Carbon) in the water column have a substantial deviation from the base run concentrations for both the short-term calibration and the long-term scenario simulations; and 2) the total (particulate plus dissolved) PCB concentrations in the water column has a noticeable difference from the base run concentrations for the short-term calibration simulation, but it has very little difference for the base run concentrations for the long-term simulation. The results from the sensitivity analyses suggest that, under the 1994-1995 PCB loading/boundary conditions/other forcing functions, the influence of primary production on the PCB concentrations in the water column is very small, especially for long-term forecast scenarios. The details on the procedures used to conduct the test and the associated results will be presented in the revised edition of the report.

11. LM2-Toxic/POM: The model did not consider ice cover in various processes (volatilization, resuspension, etc). Perhaps test the affect with a sensitivity analysis.

Modelers' Response – The POM model was applied to Lake Michigan by the National Oceanic and Atmospheric Administration (NOAA)-Great Lakes Environmental Research Laboratory (GLERL). The current version does not include ice cover algorithms. However, in the absence of an ice model, both POM and LM2 were run with the water temperature steady at 2°C from the period January 1, 1994 through March 31, 1994. Lake Michigan ice cover for 1982 and 1994 were greater than the mean and median whereas 1983 and 1995 were less than the mean and median. None of the four years (1982-1983 hydrodynamic model calibration years and 1994-1995 LMMBP years) represented an extreme of mean daily ice cover. There is an in-depth discussion on historical ice cover data for Lake Michigan in Part 1, Chapter 4 of the report.

Both NOAA and Large Lakes Research Station (LLRS) staff agree that ice cover algorithms in POM would be worthwhile additions to the model. During most winters, Lake Michigan ice cover occurs most often in the nearshore areas only. LM2-Toxic could utilize ice cover predictions from POM by indicating the fraction of the surface segment area that is covered during certain times. However, the coarse grid structure of LM2-Toxic could not be used to predict the impact of ice cover in specific small regions of the lake, such as nearshore zones. At this time, we do not have the in-house expertise to develop a revised POM that addresses ice cover; however, when a revised POM is made available from GLERL that incorporates these algorithms, we could incorporate this version into our Level 3 models where segmentation resolution is fine enough to better deal with year-to-year and within-year ice cover variations. GLERL is planning to incorporate ice cover algorithms in POM for application to Lake Erie.

The effect of ice cover on PCB mass fluxes across the air-water interface through gas absorption and gross volatilization is likely to be small because our calculations predict that these PCB mass fluxes decrease substantially with a decrease in temperature. However, it is recognized that ice cover could affect both particulate settling rates and sediment resuspension fluxes of PCBs in certain time periods in a year in the nearshore regions. It is our opinion that ice cover most likely will not have a substantial impact on the long-term results from the LM2-Toxic model, because ice cover does not affect the total inventory of PCBs in the lake system. However, for short-term predictions, ice cover would be expected to impact the model predictions.

12. LM2-Toxic/Food Chain: Investigate congener patterns in air, water, fish, and sediment. How do these compare?

Modelers' Response – The PCB patterns of multiple media will be compared to determine similarities and differences within and among media. This technique is commonly referred to as PCB fingerprinting or PCB signature recognition and has had mixed success in the past. This recommendation has minor implications to the modeling; however, it is a data analysis tool and has merit for data presentation and interpretation purposes. The relative percent of total

PCBs represented by each congener will be computed and then expressed as a cumulative frequency plot for comparative purposes. These will represent data for an entire study period, will by tested with both mean and median values, and will be a composite expression of seasonal and spatial data. In addition, selected evaluation of pattern recognition using the LMMBP data set can be found in Kuehl (2002) and McCarty *et al.* (2004).

Fingerprints will be calculated for sediment, water column (dissolved and particulate), vapor phase, wet and dry atmospheric deposition, and age 5-6 year-old lake trout signatures from the Saugatuck biota site. Atmospheric signatures will be based on a subset of all congeners because vapor phase data were computed by Keri Hornbuckle for the study, and over-lake concentrations were only calculated for the congeners that are being modeled at Grosse Ile. In addition, PCB patterns associated with water discharging from the Kalamazoo River near the Saugatuck biota site and other selected tributaries will be compared/contrasted to the lake water. These results will be presented in Part 1, Chapter 6 of the report.

13. LM2-Toxic: Consider the missing 120 kg/year total PCB contribution from Milwaukee (sum vapor/wet/dry); how sensitive is the PCB model to atmospheric and tributary loads?

Modelers' Response – The issue, documented in Wethington and Hornbuckle, 2005, of an additional PCB load from the Milwaukee area through vapor exchange, wet deposition, and dry deposition to Lake Michigan was not included in our model. The additional PCB load from the atmosphere was estimated to be at least 120 kg per year. The sensitivity analysis for the Milwaukee load was performed by adding a 120 kg/year PCB load into segment 1 in our model. The results from the sensitivity analysis were then compared to results from the LM2-Toxic model long-term (62 years) base run (Constant Conditions Scenario). The steady-state concentrations from this simulation show an increase of less than 5% in the steady-state concentration compared to the original long-term base run. The details on the Milwaukee loading sensitivity analysis and the impact of the external PCB load changes and vapor phase concentrations to the projected level of PCB concentrations in Lake Michigan will be discussed in the revised report. It should be noted that additional data will always continue to become available, and this is such a case.

Another potential missing load to the lake is that load associated with very large particles greater than 10 µm. Although experts disagree on the magnitude of the PCB load to the lake *via* large particles, various scientists indicate that PCB dry deposition associated with large particles could be a significant PCB source to the lake (Miller *et al.*, 2001; Franz *et al.*, 1998; Holsen, 1991). Currently, it is not possible to make reliable estimates of these fluxes to the lake. The uncertainty in these flux estimates is associated with the uncertainty of how far these large particles travel from their sources.

Simulations were run to gain insight into how the model would respond to increasing the total PCB load (load from all tributaries + atmospheric load to the entire lake) by 50% and 100%. The results from these sensitivity analyses were then compared with those from the LM2-Toxic model long-term (62 years) base run (Constant Conditions Scenario). The steady-state concentrations from this simulation show an increase of less than 10% and 25%, respectively, to the steady-state concentration from the long-term base run.

14. LM2-Toxic: Investigate PCB diffusion from deeper sediment layers, relative to sediment resuspension.

Modelers' Response – Because of very large PCB partition coefficients, most of the PCB mass in the sediment is associated with the particulate phase. Therefore, relative to sediment resuspension, the PCB mass moved by PCB diffusion between deeper sediment layers through pore water is trivial. Adding this process into the current semi-Lagrangian scheme for sediment transport in the LM2-Toxic model would require considerable effort and time to modify the code, calibrate the model, and analyze the output.

15. LM2-Toxic/LM Food Chain: Conduct a hindcast for PCBs which will be further used in the LM2 Food Chain hindcast; possibly select five congeners.

Modelers' Response – We agree with the review panel on the importance of this task. Although it requires significant resources, time and effort, this is an effort that is certainly worth doing. This task is currently underway and all of the selected PCB congeners (54) will be simulated in the model hindcast. The LM Food Chain model will be run using the output of the LM2-Toxic hindcast that was run to describe the exposure history. The approach, inputs, model outputs, and interpretation of the results will be presented in the revised report.

16. LM2-Toxic/POM: Examine the effects of changing the horizontal grid structure to evaluate translating POM output to the LM2 grid.

Modelers' Response – This is a valuable and interesting suggestion. However, it would require considerable effort and expertise to accomplish the task. It would require extramural personnel such as David Schwab of NOAA-GLERL to adapt POM output to the new grid structure. Considering the resources and time that would be involved in this task, it cannot be done in the foreseeable future.

17. LM-Food Chain: Calibrate over declining exposure concentrations rather than constant exposure history. To facilitate this effort, consider hindcasting five PCB congeners.

Modelers' Response – Due to the lack of credible PCB congener-specific exposure history data, the measured data for PCBs in water and sediment (1994-1995) was assumed to be representative of life-long average exposure concentrations for the food web and was, therefore, used in model calibration simulations. Model calibration over declining exposure concentrations will be attempted once the temporal profiles of congener-based PCB concentrations in water and sediment become available from the LM2-Toxic hindcast.

Theoretically, calibrations over declining exposure concentrations should yield better results than that conducted over a constant exposure history because PCB loads to the Great Lakes have been and will likely continue to decline toward a steady-state. However, it is difficult to accurately determine the rates of decline for exposure concentrations in the various media. The lake trout, as well as coho salmon food webs in Lake Michigan, are exposed to PCBs associated with both the water and sediment. Therefore, model calibrations for their food webs require information on temporal variations of PCB concentrations in both the water and sediment over the exposure history. However, the temporal trends of PCB concentrations decline are usually reported for total PCBs only. Congener-specific PCB data are rarely available. For total PCBs, the quality of the estimated exposure decline rates is usually questionable due to the often considerable variability and uncertainty of the measured total PCB data in the water and sediment. Therefore, with limited data availability and poor data quality, a reconstructed declining exposure history is not necessarily a better representation of the actual exposure condition than the constant exposure assumption. If one can assume that the PCB concentrations in Lake Michigan system is currently declining at a very small rate, then model calibrations using current congener-specific PCB data as average life-long exposure may be a more desirable alternative than model calibrations over declining exposure concentrations for total PCBs or a limited number of congeners.

18. LM Food Chain: Concern on using specific dynamic action (SDA) versus activity cost (respiration). Recommend using activity cost for calibration. This question will be re-formulated in the written review.

Modelers' Response – In the LM Food Chain model, activity cost for each species is estimated as a function of temperature based on bioenergetic equations and is not "refined" during calibrations. We chose to adjust only SDA with the hope to minimize the risk of turning calibration into a curve-fitting exercise.

19. LM Food Chain: Explain why 5.5 year-old trout data are so variable at Saugatuck.

Modelers' Response – It is not uncommon for fish to have variable PCB levels among individuals of the same age class and among age classes. The variability of PCB levels among individual fish can have a direct impact on the uncertainty interval associated with the measured PCB data in composites. The variability of an individual fish's PCB concentrations may be attributed to, among other things, the differences in body size, health condition, feeding skill, dietary preference among individual fish, exposure variances due to their spatial feeding range, and analytical chemistry variability. These individual differences are likely to have direct impact on the growth rate and the amount of dietary PCB intake of individual fish and subsequently on fish's PCB bioaccumulation.

The trend for the USEPA historical Saugatuck lake trout PCB concentration data is clearly downward. Similarly, the within-year variability represented by 95% confidence intervals for these observations also demonstrates a decreasing trend in time. Data prior to 1981 clearly have much more within-year uncertainty than data collected after that date, and the concentration means for these earlier data show greater year-to-year differences than do later composites. A cursory examination of the historical PCB lake trout composite concentration data compared against available mean fish length, fish weight, % lipids, and % males in the composites revealed no distinct relationships for the years examined.

Although a cursory examination of the historical PCB lake trout composite concentration data collected at Saugatuck compared against mean fish weight and length showed no distinct relationship, some of the within-year variability of composites could be further attributed to the fact that the monitoring samples were not collected for a particular age class. Rather, the lake trout samples were collected and classified as 600-700 mm size class. For many of the historical 600-700 mm lake trout samples, their age classes are uncertain. Based on accurate age classification for the 1994-1995 lake trout samples, the 600-700 mm size class can be roughly associated with 5 and 6 year age classes. However, this size-age correlation may not necessarily be applicable for lake trout samples collected in other years. In other words, the monitoring data for adult lake trout at Saugatuck over the years represent PCB levels in a range of age classes of lake trout. In our report, these monitoring data were labeled and plotted as PCBs in 5.5 year-old lake trout merely for convenience in comparing with age-specific modeled PCB data for lake trout. To demonstrate the range of PCB-predicted concentrations in lake trout, model output for the 4, 5, 6, and 7 year-old lake trout will be plotted with the Saugatuck historical lake trout data. This graphic will appear in the revised draft of the report.

Dietary preference is likely a very important aspect in evaluating long-term trend data. Food web changes have and are occurring in Lake Michigan based upon past and present disparate reports on the topic. However, the 1994-1995 diet study results suggest a general consistency with known lake trout diet preferences in the past. Although these are typically dominated by alewife, bloater, sculpin, and smelt, there may be a greater trend toward bottom-dwelling bloater and sculpin than during the general evidence in the past two decades.

The year-to-year differences in mean concentrations and the within-year variability observed in lake trout could also possibly be related to variable exposure resulting from meteorological and physical factors. These factors have the potential to have direct and indirect impacts on the food web and exposure gradients within the feeding range of Saugatuck lake trout. A primary factor is PCB loading events associated with high flow from the Kalamazoo River that discharges at Saugatuck. The Kalamazoo River has a history of PCB contamination (see table that follows in response to 1.20). Also, periodic low lake level events have the potential to reduce PCB exposure to the lake trout food chain in certain zones which could be reflected in periodic low-level PCB body burden results. In a period from the mid-1960s to the late-1980s, the lake levels were at near record lows and near record highs, respectively.

Much of the analytical chemistry data on fish prior to 1983 was performed using packed column gas chromatography (GC). Dichlorodiphenyl-dichloroethylene (DDE) often co-extracted with the PCBs and was very difficult to analytically separate from PCBs on the packed-column GC (Michael Mullin, personal communication). If the concentration of DDE was significant, and separation was not complete, then a positive PCB bias results in the measurement. Some measurements were performed where sample extracts were analyzed using joint GC and mass spectrophotometry. This combined analytical system improved the ability to separate the DDE from the PCBs. Most of the analytical work performed post-1983 was done using capillary GC which significantly improved separation of DDE from PCBs.

20. LM-Food Chain: Develop a time line/chronology of regulatory and remedial actions, relative to the fish monitoring record/trend at Saugatuck.

Modelers' Response – This has been done and will be found in the revised edition of the report in Part 1, Chapter 5. Where appropriate, dates have been added to figures in that chapter. The table used to summarize the time-line is shown in Table 7.1.2.

21. LM-Food Chain: Provide an estimate of model error on the fish long-term monitoring trend.

Modelers' Response — There are many sources that contribute to model errors. They include conceptual errors and/or omissions, errors in parameterization, uncharacterized system variability, and errors in data used for calibrations. In addition, the quality of model prediction of the long-term fish monitoring trend

Table 7.1.2. Significant Dates in the History of PCBs in the Lake Michigan Basin

Date	Event
1865	First PCB-like chemical discovered
1881	First PCBs synthesized
1914	Measurable amounts of PCBs found in bird feathers
1927	PCBs first manufactured at Anniston, Alabama
1935	PCBs manufactured at Anniston, Alabama and Sauget, Illinois
1948-1971	Outboard Marine Corporation at Waukegan, Illinois purchase eight million gallons of hydraulic fluid with PCBs
1954	Appleton Paper Company began using PCBs as PCB-coated carbonless copy paper with discharges to the Fox River
Mid-1950s to Mid-1960s	PCBs loaded to Kalamazoo River from deinking
1959-1972	Outboard Marine Corporation at Waukegan, Illinois used hydraulic fluid with PCBs for die-casting
1960s	PCBs used by Tecumseh Products Company loaded Sheboygan River
1969-1970	Paper company discharges of PCBs to Fox River peaked
1970	PCB production peaked at 85 million pounds and huge contamination noted at Sauget, Illinois plant
1971-1972	Appleton Paper Company and NCR Corporation phased-out PCB use. Recycling of carbonless paper had occurred for several decades
1973	U.S. Food and Drug Administration (USFDA) establish 5 ppm PCB tolerance level in fish
1975	124,000 cans of salmon from Lake Michigan seized because of PCBs
1977	PCB production ends
1984	USFDA lowered PCB tolerance level in fish to 2 ppm
1985	Commercial fishing for carp and other valuable species outlawed on Green Bay
1989-1990	Sheboygan Harbor PCB Remediation
1991	U.S. Department of Health and Human Services label PCBs as possible carcinogen
1991-1992	Waukegan Harbor PCB remediation (1 million pounds PCBs) completed for this action in 1992. Additional work is planned.
1998	The eight Great Lakes States agreed on a “Great Lakes Protocol for Fish Consumption Advisories” that lowered the regional standard from the USFDA commercial standard of 2 ppm down to 0.05 ppm
1997-1999	Kalamazoo River sediment PCB remediation on Bryant Mill Pond (20,000 pounds of PCBs). Additional work is planned
1997-1998	Milwaukee River PCB remediation
1998-1999	Upper Fox River deposit N (17,000 cubic yards) and sediment management units 56 and 57 dredging partially completed. Additional work is planned on the Fox River system
1994-2000	Manistique Harbor PCB remediation (141,000 cubic yards)
20002	Possibly begin Grand Calumet River PCB remediation

depends on the availability of a realistic projection of future exposure concentrations in water and sediment for the food web. Not all errors from these sources can be quantified. In the final report, we will provide an estimate of model error associated with model parameterization and calibration with an emphasis on error associated with a potential shift in food web structures.

22. LM Food Chain: Conduct a prey sensitivity analysis for lake trout.

Modelers' Response – We will be testing the sensitivity of the model to changes in the food web structure. In addition to a prey sensitivity analysis for lake trout at Saugatuck, model sensitivity to fish growth rate, lipid content, and temperature (among others) will also provided in the revised edition of the report.

23. Enhance data presentations of the project data to provide regional and open lake/nearshore differences and gradients for multiple media.

Modelers' Response – We agree that data presentation is an important aspect of this project to aid in the understanding of modeling results. PCB data used for the modeling will appear in the revised edition of the report in Part 1, Chapter 5, "PCBs in the Lake Michigan Ecosystem."

24. Provide CDs of presentations to the Peer Review Panel.

Modelers' Response – All presentations given at the peer review were provided to the panel members in electronic form after the review.

25. Provide CD copies of draft modeling report, appendices, and attachments (those available electronically) to the Peer Review Panel.

Modelers' Response — The Draft Modeling Report, Appendices, and Attachments were provided to the panel in bound hard-copy in late June 2004 for review purposes. CD/electronic copies of the report and associated materials were provided to the peer review panel after the review.

7.1.5 Modelers' Responses to Specific Comments Made by Peer Review Panel Member – James Martin

Note: Some of Dr. Martin's comments were identical to those listed in the consensus comments above and were, therefore, not repeated in this section.

1. MICHTOX: Continue to maintain the Level 1 model, particularly for comparison with Level 2 predictions.

Modelers' Response – While we appreciate the reviewer's interest, it would be difficult to continue to maintain the MICHTOX PCB model for purposes of comparing future Level 2 predictions because of current resource limitations. Furthermore, it is rather difficult to make a direct comparison of MICHTOX to Level 2 because the construct of the two models is so different. We plan, however, to continue with the development of a Level 3 PCB transport/fate/-bioaccumulation model which would offer much more spatial resolution and would incorporate SEDZL sediment resuspension velocities along with the QUICKEST-ULTIMATE sediment algorithms into the framework. The Level 3 model should; therefore, be very useful for comparison to the Level 2 model predictions.

2. MICHTOX, LM2, and LM3: Explore incorporating specific algorithms, such as the steady-state algorithm (as exists in MICHTOX), with the Level 2 and potentially Level 3 models.

Modelers' Responses – A steady-state version would be helpful if Monte Carlo type simulations were performed to help understand model uncertainty. For the LM2 and LM3 PCB congener-level models, a Monte Carlo type uncertainty analysis presents many challenges as described in our response to comment 8 above. However, for our other two LMMBP toxic chemicals of interest (mercury and *trans*-nonachlor), a Monte Carlo type simulation would be more feasible due to the fewer number of state variables.

3. MICHTOX/LM2: Both models predicted remarkably similar changes in total PCB concentrations over time in the long-term projections. However, there were differences between the two models such as in the rates of settling/resuspension used and in the characterization of the sediment bed. As a result, the two models predicted similar results for somewhat dissimilar reasons. It would be of interest to further investigate factors leading to the similarity in predictions, which may provide some additional insights as to the factors controlling PCBs in Lake Michigan.

Modelers' Responses – In Ken Rygwelski's PowerPoint presentation at the peer review titled, A Comparison of Lake Michigan Mass Balance Project (LMMBP) Polychlorinated Biphenyl Models: MICHTOX versus LM2-Toxic and LM Food Chain, a graphic was presented that displayed the whole lake total PCB concentration projections for the two models. It is noteworthy that at the beginning of the runs depicted, January 1, 1994, MICHTOX starts out higher than LM2-Toxic. The reason is that MICHTOX concentrations at that time represent the concentrations predicted from the MICHTOX hindcast whereas the concentrations form LM2 represent observed lake concentrations at that time. Also, note that in the same presentation MICHTOX was losing approximately 2,958 kg/year and LM2-Toxic was losing 2,043 kg/year. Although MICHTOX was losing more PCBs per year than LM2-Toxic, it started out with a higher lake inventory of PCBs in the water, which can explain, in part, why the two models predict similar concentrations. The construct of these two models is rather different in a number of ways, and this makes comparisons difficult. Some of these differences, however, were most likely overcome through the calibration process of the two models. A discussion on this topic of model comparability between MICHTOX and LM2-Toxic will appear in the revised report.

The two food chain models were also very close to predicting when the 5.5 year-old lake trout at the Saugatuck biota zone would reach the target consumption criteria of 0.075 ppm PCBs in whole fish. MICHTOX predicted year 2025 and LM Food Chain predicted the year 2026. A major difference between these two model constructs is that MICHTOX is composed of four members in the food web whereas LM Food Chain has 10 members. Also, MICHTOX is based on two PCB homologs and LM Food Chain is PCB congener-based. It is likely that much of the similarities in the predictions of these two models is due to calibration and the use of the same rate of decline for PCB loads for natural attenuation.

4. POM/LM2/LM3: Continue development of the linked POM and Levels 2/3 models.

Modelers' Response – Currently, neither in-house expertise nor funding exists to further the development of POM for Lake Michigan. We do recognize; however, that simulating ice cover and incorporating finer spacial resolution for some nearshore "hot spot" areas could be described better with a POM upgrade.

In terms of upgrading Level 3 models, we are currently working on upgrading the coupled LM3-Eutro and LM3-Toxic (PCB) model. This near-term goal includes resuspension velocities from SEDZL into the coupled model. The QUICKEST-ULTIMATE algorithm will be implemented in the 10 sediment layers. The model has two particle classes: fine-grained inorganic fraction and fine-grained organic fraction. Refractory organic carbon, total phosphorus, total nitrogen, and total silica will be associated with the particulate resuspension flux as well as the PCB modeled congeners. With this new construct, a LM3 hindcast from 1960 to 1995 will be run for both the Eutro and Toxic components of the coupled model. A long-term goal includes adding sediment diagenesis and dissolved oxygen algorithms to LM3 Eutro.

LM3-Eco is an enhanced version of LM3-Eutro and will eventually include *Bythothrephes, Mysis*, carnivorous zooplankton, herbivorous zooplankton, diatoms, and green algae (Phase 1), and additional state variables including *Dreissena, Diporeia*, nitrogen-fixing blue-green algae, and non-nitrogen-fixing blue-green algae (Phase 2). At this time, Phase 1 of LM3-Eco is in the model calibration stage.

5. Provide documentation of the POM application and testing, particularly with regard to an assessment of the applicability of the model to the transport of PCBs and other water quality constituents. Perhaps include it as an appendix to the modeling report.

Modelers' Response – See Schwab and Beletsky (1998) and Beletsky and Schwab (2001). These documents are available at http://www.glerl.noaa.gov/pubs/techrept.html and http://www.glerl.noaa.gov/pubs/fulltext/2001/20010008.pdf, respectively. LLRS has electronic and hardcopy forms of these documents in our library.

6. Investigate potential linkages issues between POM and with SEDZL.

Modelers' Response – SEDZL has its own hydrodynamic model and is not at all connected with POM; therefore, all of the hydrodynamic forcing functions are input into the SEDZL model. The Donelan parametric wind wave model applied to Lake Michigan by David Schwab of NOAA-GLERL is a stand-alone model which is run before SEDZL is run, and the output of the wave model becomes input for the SEDZL model.

7. Investigate assumptions/limitations of using a sigma grid, particularly in resolving both nearshore and open lake issues. One potential limitation to the POM model construct (relative to this application) is related to the coordinate system used in the vertical dimension (a sigma grid). A sigma grid requires a constant number of vertical layers throughout the model domain (beneath each of the 5 km horizontal grid cells (the number of vertical layers was variously cited as from 15 to 20 in the modeling report, which should be corrected). This use of the sigma grid may impact the ability of the model to resolve vertical gradients, particularly in deeper sections of the lake while still sufficiently capturing nearshore circulation patterns. In addition, sigma grids may produce artificial horizontal transport patterns. While there are numerical schemes for compensating for this, I am not aware that they have been implemented in POM or that any sigma transport tests have been conducted for an application such as Lake Michigan.

Modelers' Response – The actual number of sigma layers throughout the POM construct is 19 water layers. The citations mentioning 15 or 20 layers will be corrected in the revised edition of the report.

The potential problem of using the sigma grid structure for POM is that an extra term is introduced in the horizontal gradient terms that can lead to artificial vertical diffusion of heat and momentum, particularly in areas of large topographic gradients as was described in Schwab and Beletsky (1998). To help minimize this affect, the 5 km gridded depths were slightly smoothed by adjusting the depths to ensure that the relative depth change between adjacent grid squares was less than 0.5 while still preserving the volume of the original grid.

The model did not perform as well in the thermocline area as it performed near the surface. The simulated thermocline was too diffuse. To study the effect of vertical resolution on the vertical temperature gradients, a model run with 39 sigma levels was conducted. NOAA also ran the model with zero horizontal diffusion to test for artificial diffusion along sigma surfaces. In both cases, very little improvement was noticed in model results. On the other hand, experiments with an one-dimensional version of the model showed that the Mellor-Yamada scheme can provide a sharp thermocline that is sensitive to the choice of extinction coefficient which posses significant spatial and temporal variability in large lakes but was kept constant in the calculations because at the time of generating the model runs, temporal data on the extinction coefficients were not available. In Schwab and Beletsky, 1998, NOAA mentions that a 2 km grid structure or higher resolution would likely improve the results, but would likely push computer resources beyond current limits for the hydrodynamic model and associated LM3 water quality models.

8. In addition to spatial averaging, there was apparently time-averaging of hydrodynamic predictions as well, allowing a daily time-scale for the LM2-Toxic model. The procedures used to average the hydrodynamic predictions, and tests conducted to determine the impact of that averaging, should be documented.

Modelers' Response – Schwab and Beletsky (1998) indicate that aggregated average surface heat flux (on an hourly time scale) and average vertical temperature profiles (on a six hour time scale) were computed for each of the 10 LM2 surface segments and the 41 segments, respectively, for both the 1982-1983 and 1994-1995 periods. In addition, horizontal and vertical inter-segment transports averaged over one-day and six-day intervals were computed for the 10 column LM2 grid with five vertical layers: layer one, 0-10 m; layer two, 10-20 m; layer three, 20-30 m; layer four, 30-50 m; and layer five, 50 m-bottom. They do not discuss any tests run to determine the impact of averaging. A discussion on how these data were used in LM2 can be found in the report in Part 4, Chapter 4, Sections 4.4.1.2 and 4.4.1.3. All programs and data sets associated with the LM2 aggregation are on the Final Report CD received from NOAA-GLERL.

9. LM3-Eutro: Table 2.4.6 lists the two "types" of data but does not describe how the transformations were made.

Modelers' Response – The relationship between the variables measured in the field and state variables used in the model can be found in Appendix 2.4.1 of the report.

10. LM3-Eutro: Table 1.1.2 does not indicate that zooplankton were a measured parameter, although it is a model state variable and the text indicate that zooplankton data were collected (Part 2, Chapter 4, Section 2.4.2.2.4).

Modelers' Response – As part of the introductory material, Table 1.1.2 was only intended to offer a general overview of the major types of data collected. For example, some sub-parameters of PCBs such as a listing of all of the congeners measured, or the fact that dissolved and particulate were measured are missing from the table. However, zooplankton is a major biological and will be included in the table. A comment will be added where Table 1.1.2 is referenced in the text explaining that for a complete listing of parameters measured, the reader should see Part 1, Chapter 3 of the report. For modeled parameters, the reader should see individual chapters on MICHTOX, MICHTOX Food Chain, LM2-Toxic, LM Food Chain, or LM3-Eutro modeling in the report.

11. LM3-Eutro: While I agree that the expansion of variables to include dissolved organic and labile and refractory particulate organic forms allows for more realistic description (which is an increasingly common practice) there are no established protocols for measuring these forms. Therefore, it must have been necessary to make assumptions regarding, for example, the partitioning of particulates among labile and refractory forms. Those assumptions should be described in the report, and perhaps some sensitivity analyses performed as to the impact of differing assumptions on model predictions. The assumptions regarding the split were indicated (Part 2, Chapter 4, Section 2.4.1.1) for atmospheric loads, but not for other loading sources that this reviewer could find.

Modelers' Response – The LM3-Eutro model has labile and refractory state variables for particulate nitrogen and phosphorus whereas particulate silica is in the refractory form only. Since nitrogen was not a limited nutrient in the model, the evaluation of the two particulate nutrient forms focuses on phosphorus only.

Total phosphorus, dissolved phosphorus, and soluble reactive phosphorus (SRP) were measured in the water column of Lake Michigan. The labile and refractory forms of particulate phosphorus can be calculated based on equations described in Appendix 2.4.1. For initial lake conditions, particulate phosphorus was evenly split between the labile and refractory forms. Somewhat different fractions of particulate phosphorus were used for the labile and refractory forms in tributary and atmospheric loads (e.g. the tributary particulate was 0.55 labile and 0.45 refractory – see Part 2, Chapter 4).

The mineralization rates for the two particulate phosphorus forms used in the model were very similar; therefore, no significant differences would be expected when different fractions of these forms are used in the model. This was confirmed when several model sensitivity simulations were performed by varying the initial lake condition and loading percentages between 25% and 75% for the two particulate state variables, and in all cases the results were virtually the same.

12. LM3-Eutro: In Part 2, Chapter 4, Section 2.4.4.2, it is stated that laboratory primary production rates were used to verify the overall production rates in the model. These comparisons should be included in the modeling report.

Modelers' Response – A comparison of the model-predicted versus laboratory-measured primary production rates can be found in Figure 2.5.2. However, there was no reference to this figure in Part 2, Chapter 4, Section 2.4.4.2. (there was a reference to the graph in Part 2, Chapter 5, Section 2.5.2). The text will be updated to include a reference to the figure in Part 2, Chapter 4, Section 2.4.4.2, and the figure will be moved.

13. LM3-Eutro: The characterization of non-diatoms versus diatoms is a useful breakdown. Since blue-greens were the dominant algae (see page 99), some additional explanation would be worthwhile as to how nitrogen limitation was computed for these algae.

Modelers' Response – Blue-green algae was present in Lake Michigan in large numbers. However, because of their very small size, they made up less than 6% of the total phytoplankton carbon mass. For this reason, we lumped this group in the model as part of the "non-diatom" algae group and we assumed that phosphorus, rather than nitrogen, was the limiting nutrient. The corresponding section in the revised edition of the report will be updated to provide a better and more detailed explanation.

14. LM3-Eutro/LM3-Toxic: Continue to develop the Eutro Model, for both linkages to the Toxic Model as well as for use related to addressing conventional pollution in Lake Michigan and its tributaries/embayments.

Modelers' Response — We do plan to continue to develop the coupled LM3-Eutro and LM3-Toxic (PCB) model. SEDZL provides us with a time-variable resuspension velocity which we will use in LM3-Toxic (PCB). Current plans include the addition of particulate resuspension processes to LM3-Eutro including particulate forms of nutrients and refractory organic carbon. Eventually, we will add diagenesis to the sediment compartment and algorithms to compute dissolved oxygen. See our response to Number 4 above for additional details.

15. LM3-Eutro: Explore and document methods to relate measurable field data to model input values (e.g., refractory particulate organic matter).

Modelers' Response – This question has been answered in Number 11 above.

16. Conduct additional calibration (e.g., to nitrogen series) as an additional test of the model's performance and if the model may be used to address questions in the future with regard to conventional pollution.

Modelers' Response – Because nitrogen does not drive this model, relatively little time and effort was spent on the calibration of the different nitrogen species and was, therefore, not included in the June 2004 draft copy of the report. However, nitrogen will be fully calibrated in future modeling efforts especially when addressing lake nutrient and phytoplankton (chlorophyll-*a*) issues.

17. LM3-Eutro: The comparisons of model predictions and field data were somewhat limited in Part 2, Chapter 5. Additional comparisons should be provided, both graphical and statistical, between model predictions and observed data. Comparisons should be provided if possible for all state variables. For example, no comparisons are presently provided for nitrogen species.

Modelers' Response – In the revised edition of the report, Part 2, Chapter 5 (Calibration) was expanded and updated to include additional graphical and statistical results of the calibration process.

18. LM3-Eutro/LM3 – Toxic: Presently, the LM2- and LM3-Eutro codes specify sediment fluxes as zero order rates, which is a common practice. However, there are models of sediment diagenesis that allow prediction, rather than description, of those rates. While probably not critical in the context of using the Eutro predictions for input to the toxic model, incorporation of a sediment diagenesis model may be worthwhile should the LM3-Eutro model

be used in the future to assess eutrophication related management questions.

Modelers' Response – Sediment diagenesis will be added to LM3-Eutro. See "Modelers Response" to Number 4 above for additional planned enhancements of LM3-Eutro.

19. LM3-Eutro/POM: The linkage of the POM model with the LM3-Eutro grid was only briefly discussed. The incorporation of the QUICKEST-ULTIMATE routines from the U.S. Army Corps of Engineers CE-QUAL-ICM model should provide a suitable numerical framework for that linkage. However, the linkage of hydrodynamic and water quality models, even using a one-to-one spatial grid, is not a trivial task. For example, because of differing solution schemes, mass imbalances can occur which, if not properly treated, can accumulate and impact long-term model predictions. As such testing is required to ensure that water and constituent mass are conserved globally and locally in the linked water quality model. This testing needs to be documented and should be included in the modeling report, perhaps as an appendix.

Modelers' Response – All of these topics and issues were covered in four reports written by Ray Chapman associated with the U.S. Army Corps Of Engineers, Waterways Experiment Station which will be included in an updated version of the LM3 User Guide (Settles et al. 2002). This updated LM3 User Guide will be included as a new appendix in the revised report.

20. LM3-Eutro: The section of the report (Chapter 1) dealing with the calibration of the LM2-Eutro and LM3-Eutro was somewhat confusing, with regard to which model was calibrated against existing data.

Modelers' Response – The LM3-Eutro model is a Level 3 model with 44,042 (5 x 5 km^2) segments – there is no LM2-Eutro model. However, as part of the post-processing, the model was collapsed to a Level 2 grid, similar to the LM2-Toxic framework. This enabled a comparison of field data with model output on the Level 3 grid and on the Level 2 grid. Part 2, Chapter 5 of the report (Calibration) was updated to better explain the calibration of LM3-Eutro on the Level 2 and Level 3 segmentation schemes.

21. LM2/POM: An overlay grid, such as between the POM model and LM2-Eutro and LM2-Toxic is often more problematic than using a one-to-one spatial grid (between a hydrodynamic and a water quality model). In this application, it was suggested that linkage problems did occur, resulting in the necessity of adding "water balancing flows" (Part 4, Chapter 3, Section 4.3.3). Adding water-balancing flows is not an uncommon practice in linking three-dimensional hydrodynamic and water quality models. Typically those flows are small but without them water volume imbalances accumulate over time. However, it was indicated during presentations that in this study not including the "balancing" flows resulted in water volumes going to zero in some water quality segments (in Green Bay). This is indicative of a linkage problem that should be further investigated. In addition, the approach used to compute vertical exchanges (Equation 4.4.1) should not have been applicable if vertical flows (gross not net) were included with the hydrodynamic linkage. It is suggested that additional testing of the linkage be conducted and documented within the modeling report, perhaps as an appendix.

Modelers' Response – LM2-Eutro, referred to in sentence one, does not exist. Primary productivity is estimated by LM3-Eutro in space and time, and this information is exported to LM2-Toxic (PCB). The overlay between LM3-Eutro and POM is a one-to-one spatial grid.

We agree with Dr. Martin's comments and suggestion on the linkage between POM and LM2. The linkage problem (mass of water is not balanced in individual segment basis in LM2-Toxic model) was identified during the period of testing the linkage, and the water balancing flow was introduced to correct the imbalance. This problem was noted in a very small segment volume in Green Bay and after a run time of 70 years. See Part 4, Chapter 3, Section 4.3.3 of the report for additional discussion on this issue. The results of the test will be included as an appendix in the revised report. NOAA-GLERL performed the linkage calculations between POM and LM2, so any further investigation would need to be referred to them.

Dr. Martin is also correct on the applicability of vertical exchanges. The vertical flows provided by NOAA based on POM outputs are the net vertical flows; therefore, the vertical exchange process must be added in the overall water transport field used in LM2-Toxic model. Additional discussion and description of the method of calculating vertical exchange coefficients and calibration are documented in Part 4, Chapter 3, Section 4.3.3 and Part 4, Chapter 4, Section 4.4.1 in the report.

22. LM2-Toxic: As indicated in Part 2, Chapter 6, Section 4.6.2, the flux contributed by the diffusive term from the sediment bed was unexpectedly large relative to the resuspension flux. This may have been due to the relatively large specified diffusion coefficient used relative to the Level 1 model. In addition, it was indicated in Part 4, Chapter 6, Section 4.6.2 that the total PCB residence time for Lake Michigan were on the order of 100 days. This estimate seems low to this reviewer. It would be interesting to see how this compares to predictions from a Level 3 model which may more realistically estimate vertical exchanges in layers isolated from the water surface. The Level 3 model could be used to determine if the rapid removal may be in part an artifact of the modeling approach used in the Level 2 studies. As an example, given the rates of settling used, surface particles would require approximately one year to reach the bottom, while with a single vertical-box model it would be assumed that vertical transport is on average instantaneous.

Modelers' Response – We agree with Dr. Martin regarding the high flux contributed by diffusion between the water column and surficial sediment layer. We plan to investigate model responses in both the water column and sediment to various mass fluxes across the sediment-water interface by changing the diffusion coefficient and/or mixing length between the water column and surficial sediment as identified in Part 4, Chapter 2 of the report. There is further discussion on the diffusion coefficient used in LM2-Toxic model in Part 4, Chapter 6, Section 4.6.2 of the report. This also is one of the recommendations in Chapter 2 of Part 4. Like Dr. Martin, we also noticed that the total PCB residence time for Lake Michigan is relatively low and will do the comparison with the LM3 model when these results become available.

23. LM2-Toxic: Apply the model to refine whole-lake estimates of PCB concentrations.

Modelers' Response – Whole lake, volume-weighted average concentrations of total PCBs in the lake can be found in Part 4, Chapter 6, Section 4.6.4 of the report for various load reduction scenarios, including the "No-Effects Action."

24. LM2-Toxic: Extend the modeling framework to include other contaminants of concern (e.g., mercury).

Modelers' Response – We will extend the modeling framework to include other contaminants such as mercury and *trans*-nonachlor and believe the LM2-Toxic model would make an excellent and easy-to-use screening and diagnostic tool for helping management personnel and policy makers to understand the key processes controlling the level of the contaminant of interest in the water system.

25. LM2-Toxic: The comparisons of measured and simulated concentrations seem reasonable. However, since differences occur between factors controlling PCBs in Lake Michigan and Green Bay, the results for these two systems should be reported separately.

Modelers' Response – For LM2-Toxic, most field measured data were interpolated separately for the two systems. We also reported the two systems together and separately for model calibration results and mass budget diagnosis. See Part 4, Chapters 5 and 6 of the report for details.

26. LM2-Toxic/LM3-Toxic: The sediment bed model seems reasonable. However, some additional clarification of the semi-lagrangian method for simulating the sediment bed (Part 4, Chapter 3, Section 4.3.4.2.3) would be useful. In addition, the present construct does not allow for the tracking of materials buried out of the layer, or perhaps entrained into the layer from deeper contaminated sediments. Some

additionl development of the sediment algorithms would be useful for the Level 2 model and for incorporation into the Level 3 framework where it may be more important with regard to near-shore issues).

Modelers' Response – There is a detailed description on the semi-Lagrangian method for simulating sediment bed in the IPX model user manual (Velleux *et al.*, 2000). An algorithm for tracking masses and fluxes of both solids and PCBs in the sediment bed, including deeper sediments, has already been implemented in the LM2-Toxic model codes. We will consider additional development of LM2 sediment algorithms for incorporation into LM3 as another option. Also, see "Modelers Response" to Number 4 above for additional enhancements planned for the sediment bed model.

27. LM Food Chain: Continue to develop and refine the food chain model.

Modelers' Response – Additional calibration simulations will be run with reconstructed historical exposure PCB concentrations in water and sediment as inputs. The new calibration results will be compared with those from the constant exposure assumption. The results will be provided and discussed in the report. Further development and refinement of the model will be carried out when additional data for the lake trout food web at Sheboygan and for the coho salmon population become available.

28. LM Food Chain: Extend the calibration period to an evaluation of historical loadings and/or a period encompassing all available data (not just the 1994-1995 data set).

Modelers' Response – A new set of calibration procedures will be performed using estimated temporal profiles of historical PCB exposure concentrations in water and sediment as model inputs. All currently available field PCB monitoring data for fish in Lake Michigan will be compiled and used in the calibration. The results will be provided in the final report. However, the credibility of the calibration results will be impaired by the lack of historical information regarding food web structures and dietary shift, age-specific PCB data for lake trout, PCB data for forage fish, PCB compositional change, and congener-specific PCB values.

29. LM Food Chain: Use the model along with any revisions made to the LM2-Toxic to refine estimates of future trends in fish PCB concentrations.

Modelers' Response – As revised PCB exposure scenarios in the water and sediment provided by LM2-Toxic becomes available, new model projections of future trends in lake trout PCB concentrations will be made and reported in the final report.

30. LM Food Chain: Initiate extending the model (and data analysis) to other pollutants of concern (e.g., mercury).

Modelers' Response – It has been our intention to expand the model to other pollutants of concern, including application to other organic chemicals such as *trans*-nonachlor and mercury.

31. LM Food Chain/LM3-Eutro: Perhaps some more direct coupling of the eutrophication and food chain model could be considered in future applications to aid in addressing questions regarding impacts of changes in food chain structure on uptake of PCBs and other toxicants.

Modelers' Response – This recommendation was not addressed in the report. The possibility of direct coupling of the eutrophication and food chain models could be explored in future applications. However, the current state of understanding regarding the mechanism of fish dietary selection/adaption does not permit prediction of changes in food chain structures with eutrophication data. Further investigation is required on this topic before attempts are made to couple the food web model with the eutrophication model to address PCB uptake issues.

32. LM3-Toxic/LM2-Toxic: Continue to develop the LM-3 model in order to test against the LM2-Toxic predictions to estimate the potential impact of a more physically realistic model on lake-wide PCB impacts.

Modelers' Response – We do plan to further develop the LM3 models to compare to LM2-Toxic. See

"Modelers' Response" to comments in Number 4 above. Comparison of the models on a lake-wide basis, such as volume-weighted averages, will be performed.

33. LM3-Toxic: Continue to develop the LM3 Model in order to aid in addressing nearshore impacts which can not be addressed using the LM2 structure.

Modelers' Response – We will continue to develop LM3-Toxic and LM3-Eutro/Eco to address nearshore impacts as best as can be accomplished within the limitations of the 5 km grid structure. Much finer space scales would need to be implemented in a model, however, in order to model specific harbors associated with an Area of Concern or tributary mouths. In those cases, a finer scaled model would need to be constructed, and LM3 could be used to provide the boundary condition for this finer-scaled model construct.

34. LM3-Toxic: Continue to develop and test the linkage between the POM and LM3 models (both Eutro and Toxic), such as testing to ensure that mass conservation is maintained.

Modelers' Response – A mass conservation test was performed several years ago on LM3-Toxic using a conservative tracer. During the test, all loadings were shut off. All lake cell concentrations were equal. The model was run for two years, and no noticeable change was detected in the concentrations.

35. LM3-Toxic/SEDZL: Continue to explore linkages or incorporation of SEDZL routines in the Level 3 models. This linkage may be of particular importance in evaluating nearshore trends and issues.

Modelers' Response – We will continue to pursue linking SEDZL output to Level 3 models as described in the "Modelers' Response" to Number 4 above.

If we decide to further develop the linkage beyond the current construct, we would likely choose SEDZL-J as it is now being promoted by the experts as the better model to use versus SEDZL. SEDZL-J utilizes SED-Flume data and also allows for non-constant vertical sediment profile data. SED-Flume measures the total erosion rate on actual sediment cores and includes both the rate at which sediments are transferred to the water column (resuspension), but also the bed-load rate. SEDZL-J includes bed load and bed armoring whereas SEDZL does not. SED-Flume data as well as bulk density profiles have been collected on Lake Michigan cores by the University of California at Santa Barbara. A project to apply SEDZL-J was proposed, but funding was not available. Of course, if bedload, armoring, and non-constant vertical sediment profile data are not issues, then there does not seem to be a great advantage of SEDZL-J over SEDZL. A potential limitation of applying either SEDZL or SEDZL-J's, two-dimensional models to deeper portions of Lake Michigan during stratification exists. At this time, a three-dimensional, SEDZL-J, is not available.

The extent of this impact on our resuspension rate estimates is not known.

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